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## Evaluating River Restoration Success Using the California Rapid Assessment Method

Cara Clark  
*California State University, Monterey Bay*

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**EVALUATING RIVER RESTORATION SUCCESS USING THE  
CALIFORNIA RAPID ASSESSMENT METHOD**

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A Thesis

Presented to the

Faculty of the

Division of Science and Environmental Policy

California State University Monterey Bay

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Coastal and Watershed Science and Policy

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by

Cara Clark

Fall 2008

**CALIFORNIA STATE UNIVERSITY MONTEREY BAY**

The Undersigned Faculty Committee Approves the

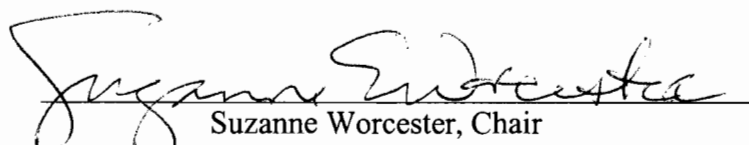
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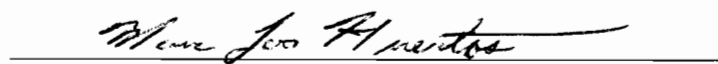
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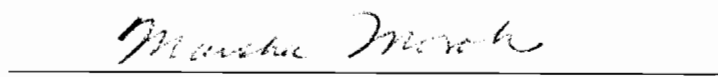
Coastal and Watershed Science and Policy

**EVALUATING RIVER RESTORATION SUCCESS USING THE  
CALIFORNIA RAPID ASSESSMENT METHOD**

  
Suzanne Worcester, Chair  
Division of Science and Environmental Policy

  
Marc Los Huertos  
Division of Science and Environmental Policy

  
Gage Dayton  
Moss Landing Marine Laboratories, Moss Landing CA

  
Marsha Moroh, Dean  
College of Science, Media Arts, and Technology

December 2008

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Cara Clark

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## **DEDICATION**

This work is dedicated to water, which is life.

## ABSTRACT

Evaluating River Restoration Success Using the  
California Rapid Assessment Method

by

Cara Clark

Master of Science in Coastal and Watershed Science and Policy  
California State University Monterey Bay, 2008

Although there has been significant expenditure on stream restoration, no unified monitoring and assessment strategy for these projects exists. This study evaluates California's success at improving stream condition by assessing state-sponsored restoration projects and comparing them to high quality reference sites using the California Rapid Assessment Method (CRAM). CRAM evaluates stream condition using universal attributes that are each evaluated with specific metrics. Restoration sites were randomly selected from a database of restoration projects in California Regional Water Quality Control Board Region 3, the Central Coast. Reference sites were chosen to characterize the best attainable condition in the region. CRAM scores for restoration sites were significantly lower than for reference sites ( $p < 0.001$ ). Discriminant analysis showed that the overall hydrology attribute and specifically the channel stability metric were the most important variables in distinguishing between restoration and reference sites. When fish passage projects were removed from the analysis, the buffer metric was targeted in the discriminant analysis. Physical structure metrics had the largest difference in means between restoration and reference sites. Practitioners have been most successful in restoring landscape and biological aspects of streams. Future restoration efforts should provide adequate buffer and aim to restore fully functioning hydrology and physical attributes. This study shows how CRAM can be used to monitor and assess river restoration projects to improve future efforts. The next steps are to build a dataset of pre- and post-restoration CRAM assessments, and to gather support for standardized monitoring among restoration practitioners and funding agencies.

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## **CHAPTER 1**

### **INTRODUCTION**

More than one-third of rivers in the United States are impaired or polluted (EPA 2002). Extensive engineering has eliminated natural fluvial dynamics, resulting in a decline in habitat and species diversity (Rohde et al. 2004). Anthropogenic modifications of river systems such as impoundment and groundwater extraction have impaired rivers so they can no longer meet human needs or provide quality habitat (Stromberg 2001). There is growing public pressure to restore degraded aquatic habitat in the United States (Bohn and Kershner 2002). Stream restoration activities have increased significantly in developed nations in the last two decades (Shields et al. 2003a).

Stream rehabilitation projects are motivated by a wide variety of goals and objectives. These include habitat improvement for target species, usually endangered or rare species (Koning et al. 1998, Champoux et al. 2003, Roni et al. 2005). On the west coast of the U.S. anadromous fish such as salmon and steelhead trout are targeted by many stream restoration projects (Bash and Ryan 2002). Millions of dollars are spent each year on fish habitat restoration in the Pacific Northwest alone (Roni et al. 2002). Other objectives include improving water quality (Zhang et al. 2005, Fennessy and Cronk 1997), removing non-native species and re-establishing native vegetation (Webb and Erskine 2003), restoring physical structure (Stromberg 2001), reducing excess sediment (Bond and Lake 2005), restoring hydrogeomorphological processes (Amoros 2001), stabilizing channels, controlling erosion, and improving flood control (Kondolf 1996). River managers are making a shift from rigid engineered structures to ecologically integrated restoration of degraded or at-risk aquatic systems (Rohde et al. 2004, Palmer et al. 2005).

Among all the different types of ecosystems, aquatic systems provide the largest suite of ecosystem services in a per-acre valuation (Costanza et al. 1997). The economic

value of services provided by wetlands in their natural state has been calculated as greater than the profits available in converted uses (Brown and Lant 1999). Water quality improvements from restoration of riparian zones may provide greater economic benefits than allocating the same land to crops (Fennesy and Cronk 1997). Restoration of streams in areas of intensive human land use provides a compromise between providing for human needs and maintaining stewardship of riparian areas. There has been a shift in policy over the last 50 years toward stewardship rather than conversion, as wetlands have been recognized for the wide variety of beneficial functions that they provide (USFWS 2000).

Aquatic resources and efforts to protect and regulate wetlands and rivers have generated extreme controversy (Baumgartner 2005). Conservationists fear that not enough is being done to protect wetlands, while advocates of property rights and development interests view wetland protection as detrimental to the economy and their individual rights (Zinn and Copeland 2006). There is a conflict of interest between those who derive benefits from aquatic resources in their natural state and property owners who wish to use them for other purposes, including real estate development, agriculture, or oil and gas extraction (Brown and Lant 1999). However, it is possible to combine engineered flood control projects in urban streams with habitat enhancement for endangered anadromous fish species (Larson et al. 2001).

California's investment in river restoration has received public support through voter approved ballot measures such as Propositions 13, 40, 50, 84 and other state funded programs aimed at restoring the integrity of the state's waters (SWRCB 2006a), comprising a total of \$2.1 billion in public funds (SWRCB 2007). The rise in investment in stream restoration projects spurs the need for clear and scientifically based guidelines for restoration. Guidelines have been published for the United States (NRC 1992, Roni et al. 2005) as well as internationally (SER 2004). There is growing recognition of the importance of river restoration, however there is no consensus on what makes a restoration project successful (Palmer et al. 2005). The difficulty in defining success is tied to the lack of unified focus on restoration goals (Kentula 2000). Restoration projects

are undertaken for a wide variety of reasons, and have myriad goals and objectives among projects (Kondolf 1996). This is not a problem unless one wants to define success criteria across the range of projects. Here I provide details on various methods used to evaluate restoration success.

Evaluating the success of stream restoration projects is crucial to adaptive management and improving the effectiveness of future projects (Woolsey et al. 2007). Palmer et al. (2005) attempted to define ecologically successful river restoration, and came up with five success criteria, which they called standards for ecologically successful river restoration. These standards include: 1) restoration design should be based on a template of a dynamic, healthy river that could exist at a given site, 2) measurable ecological improvement, 3) self-sustaining systems resilient to external disturbances, 4) no lasting harm inflicted by the construction of a project, and 5) performance of pre- and post-assessment and public availability of that data (Palmer et al. 2005). This paper generated discussion and debate in the ecological restoration community.

Jansson et al. (2005) returned a comment on Palmer et al. (2005), pointing out that self-sustaining systems are difficult to define and measure, especially in terms of time scales necessary for systems to recover to some desired threshold. They recommended that an explicit timeframe be defined to evaluate the results of restoration. They also proposed a sixth standard for restoration, which requires a conceptual model or hypothesis about the ecological mechanisms which will achieve the desired outcome. They suggest that this type of conceptual model will aid in the integration of science with restoration practices (Jansson et al. 2005). Gillilian et al. (2005) commented that pre- and post- project assessment is crucial and should be incorporated into funding agency requirements. They concur with the concept of designing a restoration project based on a template of a healthy river, but note that a sound design vision can be diluted in the implementation process. For example, dynamic morphology can be compromised through the introduction of hard engineered structures to avoid flooding risk or erosional damage to properties (Gillilian et al. 2005). One way to create a conceptual model for

restoration and to evaluate projects post-restoration is to compare them to reference condition.

The most common approach to defining reference condition is to assess conditions at a set of sites that are least disturbed by human activity (Stoddard et al. 2006). Studying the distribution of a set of reference sites compared to a set of sites of interest is termed the “reference site approach” (Stoddard et al. 2006). Stoddard (2005) recommends the use of regional reference sites. Ecological regions delineate areas of similar climate, landform, soil, vegetation, and hydrology, and it is reasonable to set expectations for river health within the context of an ecoregion (Stoddard 2005). Regional reference sites provide a sound foundation to evaluate restoration sites (Ambrose et al. 2006). Another approach uses paired reference sites in the same or an adjacent watershed to compare to a restoration project. Paller et al (2000) measured fish assemblages in two reference sites and two sites impacted by releases of power plant cooling water from nuclear reactors. This approach is useful for detailed studies at a local scale, but regional reference condition is more effective for evaluation of multiple restoration sites.

Stoddard et al. (2006) recommend carefully specifying what is meant by “reference condition.” They proposed several terms to refer to various concepts of reference condition: “minimally disturbed condition”; “historical condition”; “least disturbed condition”; and “best attainable condition”. This study seeks to represent the “best attainable condition” for natural streams in the region. Reference sites should reflect a state that is within the realm of attainment for restoration sites. Reference sites have limited human influence, but are not the most pristine streams in the entire region.

Although there has been significant expenditure on stream restoration, no unified monitoring and assessment strategy for these projects exists (Kondolf and Micheli 1995, Bash and Ryan 2002). A nationwide study of river restoration projects found that only 10% of projects reported any type of post-project monitoring or assessment (Bernhardt et al. 2005). Of the small proportion that implemented monitoring, most were not designed to evaluate success or effectively communicate lessons learned to other practitioners

(Bernhardt et al. 2005). Restoration science lacks a comprehensive assessment of the ecological effects of stream restoration. An evaluation of restoration projects will provide crucial information on potential improvement from funds spent on restoration. This information will improve wetland management and regulatory decision making (Sutula et al. 2006). This thesis project evaluates California's success at improving stream condition by assessing state-sponsored restoration projects and comparing them to high quality reference sites.

Stream restoration is a best management practice funded and implemented by the state of California. This project will evaluate the effectiveness of stream restoration, which is a priority for the State Water Resources Control Board (SWRCB 2006b). This project is part of a larger effort to integrate monitoring efforts in California with the U.S. Environmental Protection Agency's Elements of a State Water Monitoring and Assessment Program for Wetlands (USEPA 2006). Under these guidelines the EPA recommends a three-tiered monitoring framework. The framework includes Level 1, inventory (maps of wetland resources); Level 2, rapid assessment; and Level 3, intensive assessment (USEPA 2006). California's Surface Water Ambient Monitoring Program uses this framework to keep track of the condition of the state's waters (Connor 2008). An inventory of stream projects (Level 1) was the sampling universe for this project, and after projects were selected from a Level 1 inventory, they were assessed using CRAM, a Level 2 tool.

Many local, state and federal agencies control permitting and regulatory structures for stream restoration projects in California. Local agencies such as Monterey County require permits for significant grading (Monterey County 2008). The Department of Fish and Game regulates streambed alteration through their Section 1600 permit program (CDFG 2008). The State Water Resources Control Board and the Regional Boards under it administer the Clean Water Act Section 401 to regulate discharge of pollutants into waters of the United States (SWRCB 2008). The US Army Corps of Engineers issues permits for dredging or filling of waters of the United States under Section 404 of the Clean Water Act (DWR 2008). The US Fish and Wildlife Service has jurisdiction over



actions that may affect endangered species listed under the federal Endangered Species Act (DWR 2008). These various agencies may issue permits for grant-funded restoration projects or require stream restoration as mitigation for impacts of other actions.

This project evaluates the condition of state-funded stream restoration efforts using the California Rapid Assessment Method (CRAM). CRAM was developed by a team of state and federal agency representatives and scientists as a rapid assessment tool to provide information about the ecological condition of wetlands (including streams, rivers, estuaries, vernal pools, playas, slope wetlands such as seeps, and depressional systems such as ponds and freshwater marshes) (Collins et al. 2007). A CRAM assessment results in a percentage score that reflects the current ecological condition of the stream site. CRAM assesses condition based on four primary attributes; landscape context, hydrology, physical structure, and biotic structure. Each attribute is assessed using specific metrics and sub-metrics. For example the landscape attribute is evaluated with the landscape connectivity metric and the buffer metric.

CRAM provides a rapid, cost-effective, scientifically defensible and repeatable method to evaluate restoration sites relative to reference condition (Sutula et al. 2006). Restoration projects are often constrained by limited budgets. Meeting all of the standards recommended by Palmer et al. (2005) would take significant funds in addition to funding required to actually implement a project. Pre- and post-project monitoring requirements from a funding agency, as recommended by Gillilian et al. (2005), would be a significant step toward achieving these standards. The California State Water Resources Control Board requires post-project evaluation and monitoring for their funded projects (SWRCB 2006a). However, some funding programs only provide funds specifically for implementation. CRAM provides a cost-effective tool to measure ecological improvement by performing pre- and post-project assessments. This study is constrained to post-project assessments, but the comparison to reference sites assesses the success of restoration projects in the context of regional aquatic condition.

The goal of this study is to evaluate restoration projects relative to reference condition, and to highlight potential improvements for future restoration projects. It will

target which aspects of the biophysical system need to receive increased attention by restoration practitioners. Among CRAM attributes and metrics, I will identify the greatest discrepancy between restoration sites and reference condition. CRAM Metrics separate aspects of river health into discrete categories, and these can be used to target the deficiencies of current restoration projects. This information can inform future river restoration efforts so their effectiveness will be enhanced.

## **CHAPTER 2**

### **EVALUATING RIVER RESTORATION SUCCESS USING THE CALIFORNIA RAPID ASSESSMENT METHOD**

#### **ABSTRACT**

Although there has been significant expenditure on stream restoration, no unified monitoring and assessment strategy for these projects exists. This study evaluates California's success at improving stream condition by assessing state-sponsored restoration projects and comparing them to high quality reference sites using the California Rapid Assessment Method (CRAM). CRAM evaluates stream condition using universal attributes that are each evaluated with specific metrics. Restoration sites were randomly selected from a database of restoration projects in California Regional Water Quality Control Board Region 3, the Central Coast. Reference sites were chosen to characterize the best attainable condition in the region. CRAM scores for restoration sites were significantly lower than for reference sites ( $p < 0.001$ ). Discriminant analysis showed that the overall hydrology attribute and specifically the channel stability metric were the most important variables in distinguishing between restoration and reference sites. When fish passage projects were removed from the analysis, the buffer metric was targeted in the discriminant analysis. Physical structure metrics had the largest difference in means between restoration and reference sites. Practitioners have been most successful in restoring landscape and biological aspects of streams. Future restoration efforts should provide adequate buffer and aim to restore fully functioning hydrology and physical attributes. This study shows how CRAM can be used to monitor and assess river restoration projects to improve future efforts. The next steps are to build a dataset of pre- and post-restoration CRAM assessments, and to gather support for standardized monitoring among restoration practitioners and funding agencies.

#### **INTRODUCTION**

More than one-third of rivers in the United States are impaired or polluted (EPA 2002). Extensive engineering has eliminated natural fluvial dynamics, resulting in a decline in habitat and species diversity (Rohde et al. 2004). Anthropogenic modifications of river systems such as impoundment and groundwater extraction have impaired rivers

so they can no longer meet human needs or provide quality habitat (Stromberg 2001). There is growing public pressure to restore degraded aquatic habitat in the United States (Bohn and Kershner 2002). Subsequently, stream restoration activities have increased significantly in developed nations in the last two decades (Shields et al. 2003a). California's investment in river restoration has received public support through voter approved ballot measures such as Propositions 13, 40, 50, 84 and other state funded programs aimed at restoring the integrity of the state's waters (SWRCB 2006a), comprising a total of \$2.1 billion in public funds (SWRCB 2007). Although there has been significant expenditure on stream restoration, no unified monitoring and assessment strategy for these projects exists (Kondolf and Micheli 1995, Bash and Ryan 2002).

A nationwide study of river restoration projects found that only 10% of projects reported any type of post-project monitoring or assessment (Bernhardt et al. 2005). Of the small proportion that implemented monitoring, most were not designed to evaluate success or effectively communicate lessons learned to other practitioners (Bernhardt et al. 2005). Restoration science lacks a comprehensive assessment of the ecological effects of stream restoration. An evaluation of restoration projects will provide crucial information on enhancement of streams as a result of funds spent on restoration. This information will improve wetland management and regulatory decision making (Sutula et al. 2006). Evaluating the success of stream restoration projects is crucial to adaptive management and improving the effectiveness of future projects (Woolsey et al. 2007). This study evaluates California's success at improving stream condition by assessing state-sponsored restoration projects and comparing them to high quality reference sites.

The most common approach to defining reference condition is to assess conditions at a set of sites that are least disturbed by human activity and use these to compare to sites of interest, termed the "reference site approach" (Stoddard et al. 2006). Ecological regions delineate areas of similar climate, landform, soil, vegetation, and hydrology, and it is reasonable to set expectations for river health within the context of an ecoregion (Stoddard 2005). Regional reference sites provide a sound foundation to evaluate restoration sites (Ambrose et al. 2006). Another approach uses paired reference

sites in the same or an adjacent watershed to compare to a restoration project. Paller et al. (2000) measured fish assemblages in two reference sites and two sites impacted by releases of power plant cooling water from nuclear reactors. This approach is useful for detailed studies at a local scale, but regional reference condition is more effective for evaluation of multiple restoration sites. Stoddard et al. (2006) recommend carefully specifying what is meant by “reference condition.” They proposed several terms to refer to various concepts of reference condition: “minimally disturbed condition”; “historical condition”; “least disturbed condition”; and “best attainable condition”. This study seeks to represent the “best attainable condition” for natural streams in the region (Stoddard et al. 2006). Reference sites should reflect a state that is within the realm of attainment for restoration sites. Reference sites have limited human influence, but are not the most pristine streams in the entire region.

There are many ways to evaluate aquatic systems including the reference site approach. Some are more intensive and require extensive data collection and lab analysis, while others are faster and give a general overview of a site. The Index of Biotic Integrity (IBI) is one example of an intensive assessment that uses biologic communities to define condition at a site (Karr 1991). This type of assessment is limited in scope because of the time and expense required, but it does provide an in-depth look at specific sites. Rapid assessments can encompass a broader scope because minimal time and funding is required.

This study evaluates the condition of state-funded stream restoration efforts using the California Rapid Assessment Method (CRAM). CRAM was developed by a team of state and federal agency representatives and scientists as a rapid assessment tool to provide information about the ecological condition of wetlands (including streams and rivers) (Collins et al. 2007). A CRAM assessment results in a percentage score that reflects the current ecological condition of the stream site. CRAM assesses condition based on four primary attributes; landscape context, hydrology, physical structure, and biotic structure. Each attribute is assessed using specific metrics and sub-metrics. For example, the landscape attribute is evaluated with the landscape connectivity metric and

the buffer metric. A poor score in the landscape context attribute reflects a high degree of anthropogenic stress at a particular site, for example a stream that has very little buffer between the riparian corridor and urban development, or a buffer zone that is degraded and impacted by invasive weeds. A high scoring site in the landscape context attribute is generally surrounded by open space with little impact by roads or development.

In general, a low scoring stream is impacted by urban or agricultural development, has a low degree of physical habitat complexity, and a plant community with low diversity and/or invasive weeds. For example, the Los Angeles River as it flows through urban areas would receive a low score, as it is constrained on both sides by urban development, and the channel itself is artificially hardened and therefore lacks physical habitat structures such as boulders, pools, or point bars. Water sources are artificial and the plant community is at best highly invaded and at worst nonexistent. A stream with a high CRAM score has minimal impacts from human uses, a stable channel connected to a functioning floodplain, diverse physical habitat, and a diverse plant community without invasive species.

CRAM provides a rapid, cost-effective, scientifically defensible and repeatable method to evaluate restoration sites relative to reference condition (Sutula et al. 2006). This study uses a regional reference site approach to compare restoration sites to high quality reference sites within the region using CRAM. The goal of this study is to evaluate restoration projects relative to reference condition, and to highlight potential improvements for future restoration projects. It will target which aspects of the biophysical system need to receive increased attention by restoration practitioners. Among CRAM Attributes and Metrics, I will identify the greatest discrepancy between restoration sites and reference condition. CRAM Metrics separate aspects of river health into discrete categories, and these can be used to target the deficiencies of current restoration projects. This information can inform future river restoration efforts so their effectiveness will be enhanced.

## **METHODS**

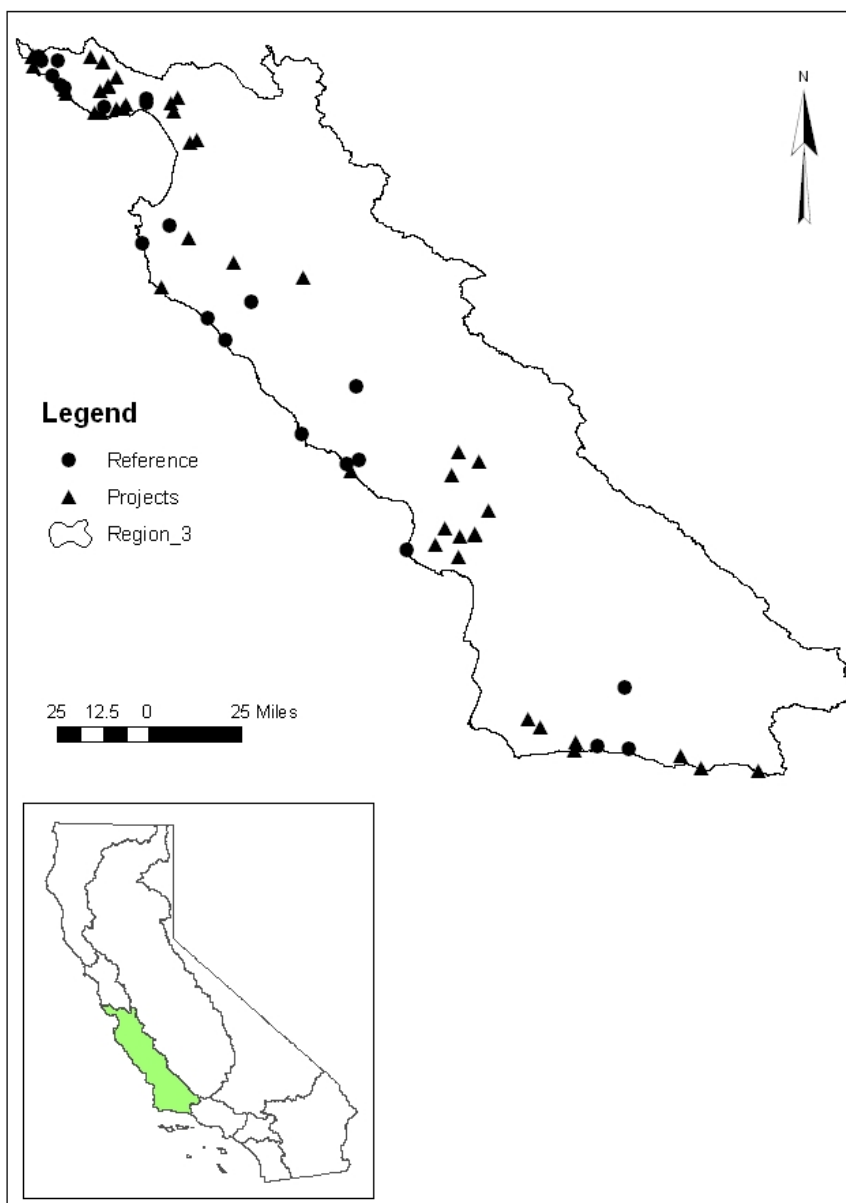
### **I. SITE SELECTION**

Restoration projects were compiled into a database that became the sampling universe for the study. These included state-funded restoration projects in California State Water Resources Control Board Region 3, the Central Coast of California (Figure 1 inset). “Restoration projects” for this study included only actual on-the-ground activities at stream sites (e.g. fish passage improvement, native re-vegetation, or restoration of natural channel morphology). Projects that only included planning, outreach, education, land acquisition, or monitoring were eliminated from the final database.

All of the available restoration project tracking databases were used as sources to catalog restoration projects in the Central Coast (CDFG 2006, California State Parks 2007, Hurd 2005, NRRSS 2005). These were combined to encompass the broadest scope of restoration projects, and because no single database contained all of the restoration projects in the region (see Appendix A for a list of databases). Information about local efforts was also provided by practitioners at Return of the Natives and Moss Landing Marine Laboratories. Only projects that took place between 1990 and 2006 were included, to reduce bias against projects that are too recent or too old to be included in project databases. Duplicate records were removed, and the records with the most complete information were retained. Sampling sites for this study were randomly selected from the final database. Some sites were eliminated if access was denied or they did not meet the selection criteria (they were not state-funded, not riverine, or were never implemented). Forty-five sites were assessed (Figure 1). Project implementers were contacted to obtain project details, monitoring reports and final reports.

Reference site selection was based on the process used by Ambrose et al. (2006). We drew on the advice of local experts from government agencies, environmental consulting groups, and the private sector. We also consulted maps, aerial photographs, and the internet to locate sites in preserves or other open space areas.

## Sampling Locations



**Figure 1. Stream restoration sites and reference sites assessed in the Central Coast of California (State Water Resources Control Board Region 3 shaded on inset map of California)**



The Ambrose study used data from the CRAM calibration teams, which had assessed a wide range of wetland conditions in the state. They chose reference sites from this dataset based on qualitative assessments of overall wetland condition made by the calibration teams (Ambrose et al. 2006). Their study included 11 riverine reference sites in the Central Coast, which were re-assessed for this study. Eleven additional sites were chosen using similar methodology, for a total of 22 reference sites (Figure 1). These are a set of “best attainable condition” reference sites within the Central Coast region (Stoddard 2005).

## **II. SITE ASSESSMENT**

All sites were evaluated using the California Rapid Assessment Method (CRAM). A CRAM assessment can be completed by a team of two to three people in less than half a day (Collins et al. 2007). The expertise required to implement CRAM is similar to a jurisdictional delineation (Collins et al. 2007).

CRAM first classified riverine systems as confined or unconfined. This classification was based on system morphology. In unconfined systems, the stream had room to migrate across a valley floor that is at least twice the average bankfull width of the channel. In confined systems, the width of the valley was less than twice the average bankfull width (Cowardin et al. 1979). A river could be confined by a narrow valley or by unnatural levees or other manmade structures (Collins et al. 2007). The next step delineated an Assessment Area (AA). This is a reach of the river small enough to assess in a maximum of a few hours, and defined by hydro-geomorphic integrity, without significant changes in inputs of water or sediment. The lateral width of the AA was defined by the extent of riparian vegetation, or if the boundary of riparian vegetation was indistinct, the lateral extent was twice the Site Potential Tree Height (SPTH). For example, if the dominant over-story consisted of willows and cottonwoods 8 meters tall, then the AA based on SPTH extended landward 16 meters (Collins et al. 2007).

CRAM used four primary attributes to evaluate condition; landscape context, hydrology, physical structure, and biotic structure. Each of these attributes was assessed based on several metrics and sub-metrics (Table 1). For example, the metrics associated

with landscape context were buffer and landscape connectivity. Some metrics were combinations of sub-metrics, such as the plant community metric, which was composed of the number of plant layers, number of co-dominant species, and percent invasion (Table 1).

**Table 1. CRAM structure with descriptions of metrics and sub-metrics**

| Attribute          | Metric                                | Sub-Metric        | Description  |
|--------------------|---------------------------------------|-------------------|--|
| Landscape Context  | Landscape Connectivity                |                   | Riparian corridor connectivity                         |
|                    | Buffer                                | % with Buffer     | Buffer perimeter                                       |
|                    |                                       | Buffer Width      | Average width  |
|                    |                                       | Buffer Condition  | Degree of disturbance, quality of buffer               |
| Hydrology          | Water Source                          |                   | Anthropogenic inputs                                   |
|                    | Channel Stability                     |                   | Equilibrium, aggradation or degradation                |
|                    | Hydrologic Connectivity               |                   | Connection to floodplain                               |
| Physical Structure | Physical Patch Richness               |                   | Presence of habitat structures                         |
|                    | Topographic Complexity                |                   | Variation in elevation and moisture gradients          |
| Biotic Structure   | Plant Community                       | # of Plant Layers | # of vertical height classes                           |
|                    |                                       | Species Richness  | # of co-dominant species                               |
|                    |                                       | % Invasion        | % of co-dominants that are invasive (based on Cal-IPC) |
|                    | Horizontal Interspersion and Zonation |                   | Inter-fingering of plant community zones in plan view  |
|                    | Vertical Biotic Structure             |                   | Degree of vertical overlap of plant height classes     |

Each metric was graded A through D, based on mutually exclusive narratives that delineate boundaries between scores. The letter grade was converted to a numeric score. Metrics within each attribute were combined to yield an attribute score, and these were

averaged for an overall percentage score for the site, with each Attribute equally weighted (Collins et al. 2007).

Geographic Information Systems (GIS) maps of project areas were produced prior to field assessment, using digital orthophoto imagery from the National Agricultural Imagery Project (NAIP). These assisted in delineation of the Assessment Area and determination of CRAM metrics in the landscape context attribute. Each map had standard elements such as a north arrow and a scale bar in meters, for use in assessing buffer width and landscape connectivity metrics.

The upstream and downstream ends of the Assessment Area were recorded in the field using a GPS (Global Positioning System) Garmin handheld Map 60 unit. The  $\pm 3$  meter accuracy of the Garmin Map 60 was sufficient for the purposes of this project.

Some restoration projects encompassed an area too large to evaluate with a single CRAM assessment. In this case I adapted the protocol used by Ambrose et al. (2006) for assessing large sites. If the large site appeared to have fairly uniform characteristics throughout, a single Assessment Area (AA) was chosen randomly and used to assess the site. If there was significant heterogeneity within the restoration site, it was stratified into homogeneous sections, and a representative AA was chosen from each of the uniform sections. The scores for each sub-section were averaged to yield an overall score for the entire restoration project.

### **III. STATISTICAL ANALYSES**

All analyses were conducted using the R statistical program version 2.4.1. R code and comments are included as Appendix B. Each attribute and metric and the overall CRAM score was tested for a significant difference in means between restoration and reference sites using a standard t-test. Where information on the age of the restoration project was available, data was tested for a significant correlation between age of the project and overall CRAM score (N=39)

I used MANOVA to test the hypothesis that there is a difference between restored sites and reference sites. The MANOVA analysis tested for an effect of multiple attributes or metrics combined rather than targeting individual variables as the t-test did.

Site character was a single categorical factor (site character = reference or restored). This type of MANOVA is equivalent to Hotelling's  $T^2$  test (Everitt 2005). I calculated two MANOVA analyses, the first based on the four CRAM attributes: landscape context, hydrology, physical structure, and biotic structure. The second MANOVA tested the difference between reference and restored sites based on the ten CRAM metrics.

I used a discriminant analysis to identify factors that influence the distinction between restored sites and reference sites. Discriminant analysis explains the difference between two or more groups, and assigns samples to a group (Green 1971). Discriminant analysis can also be used to predict group membership, or it can be used to describe variables that determine differences between groups. For example, one could predict whether a species will be present at a given site based on environmental variables (McGarigal et al. 2000). These two approaches are termed "Descriptive" and "Predictive." This study uses the descriptive facet of discriminant analysis to describe the factors that most influence the differences between the two groups (reference and restored). Discriminant analysis is used to investigate multiple variables at the attribute and metric levels. CRAM metrics can be viewed as categorical variables, where each metric or attribute has a finite number of distinct outcomes. The Attribute scores are a percentage of a total possible score, and thus are continuous variables. Discriminant analysis can be used for both categorical and continuous variables, although categorical data is likely to violate some of the distributional assumptions, particularly multivariate normality (McGarigal et al. 2000). Discriminant analysis has no specific rule for sample size, but there are some general rules. There must be at least two more samples than the number of variables and at least two variables per group (Johnson 1981). This project assesses 45 restored sites and 22 reference sites, for a total of 67 sampling entities. This was well above the limit which would require at least fourteen samples since there were at most twelve variables.

Analyses were calculated for the entire dataset and also on a subset that excluded fish passage improvement projects. These projects were often aimed at single point barriers to fish passage, but did not address overall conditions in the stream. Many had

hardened structures such as fish ladders. They were separated to investigate all the other types of projects without the potential bias from these specific projects, the remaining 31 projects. An additional discriminant analysis included each of the plant sub-metrics instead of the combined plant community metric. This was aimed at understanding the factors driving the difference between reference and restored sites in the biotic structure.

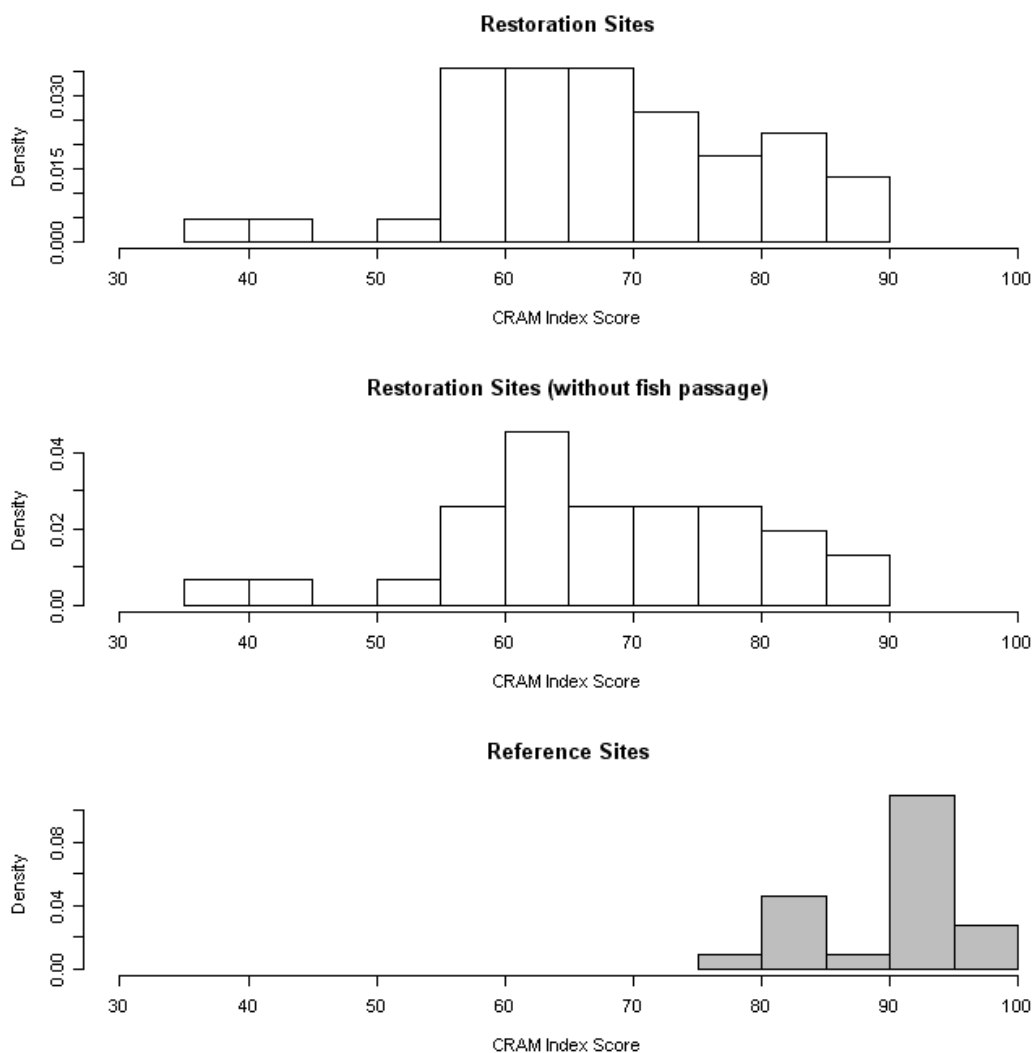
I tested the data for equal variances using Levene's test ( $\alpha < 0.01$ ) (McGarigal et al. 2000). Normality was assessed using a Q-Q plot of the residuals from a general linear model on each variable (Dalgaard 2002). I used the arcsin square root transformation to improve normality and equality of variances (Zar 1999). This was the most effective transformation in correcting for deviations from normality and homoscedasticity, for all metrics except landscape connectivity. This transformation was applied to the whole dataset, because applying different transformations to various metrics skewed the results.

The analysis with all variables transformed using arcsin square root did not meet all of the assumptions, mainly because the landscape connectivity metric diverged from normality under this transformation. However, discriminant analysis is not sensitive to departures from normality (Tabachnik and Fidell 2001). The validity of the analysis can be tested by looking at the accuracy of predictions using the discriminant function (McGarigal et al. 2000). Although group membership prediction is not the purpose of this study, it can be used to evaluate the strength of the analysis in spite of departures from normality. I ran the discriminant analysis multiple times, leaving one sample out each time, and using the rest to create a function that assigns group membership to the remaining sample, often called jack-knifed prediction (Tabachnik and Fidell 2001). Reference sites were accurately classified 90.9% of the time, and restoration sites had 82.6% accuracy. The relatively high level of accuracy suggests that the slight non-normality is not unduly influencing the results. Another study that used discriminant analysis reported percent accuracy between 15 and 39% (Ostermiller and Hawkins 2004). Although their study involved more groups and had a different purpose, the range of accuracy they obtained provides evidence that 80-90% accuracy is quite high. Another

example of jack-knifed classification had 54% accuracy, still low relative to this (Tabachnik and Fidell 2001).

## RESULTS

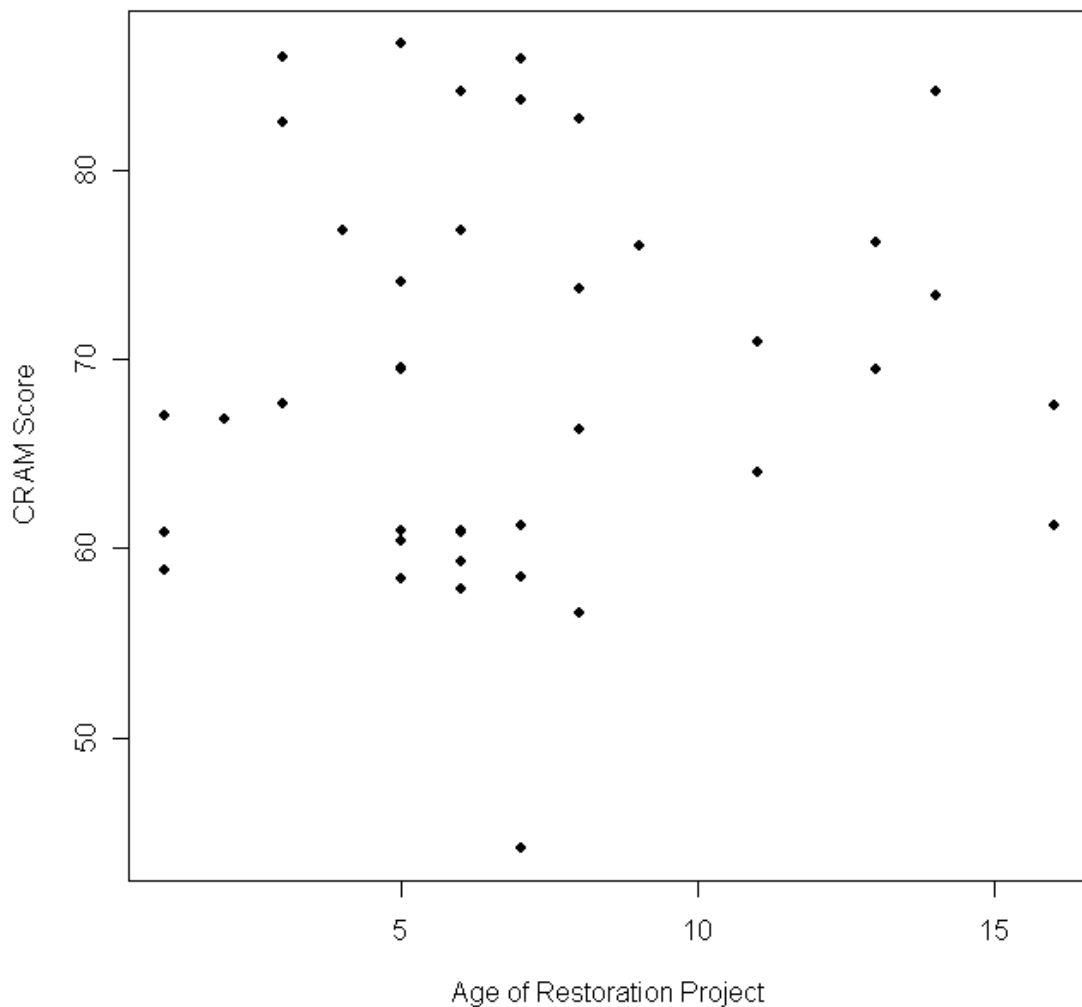
Reference sites had significantly higher overall CRAM scores than restoration sites ( $t = 8.9$ ,  $df = 65$ ,  $p < 0.001$ ;  $\bar{x}_{\text{restored}} = 67.8$ ,  $\bar{x}_{\text{reference}} = 90.3$ ). Figure 2 shows the distribution of overall CRAM scores for restoration and reference sites. The plot of the entire dataset is concentrated in the middle range, whereas the plot without the fish passage projects is more spread out at the upper end of the range (Figure 2).



**Figure 2. Distribution of overall CRAM scores for restoration and reference sites**

Half of the reference sites were in unconfined systems, and half were confined. Of the restoration project sites, 73% were in unconfined systems, and 17% were confined.

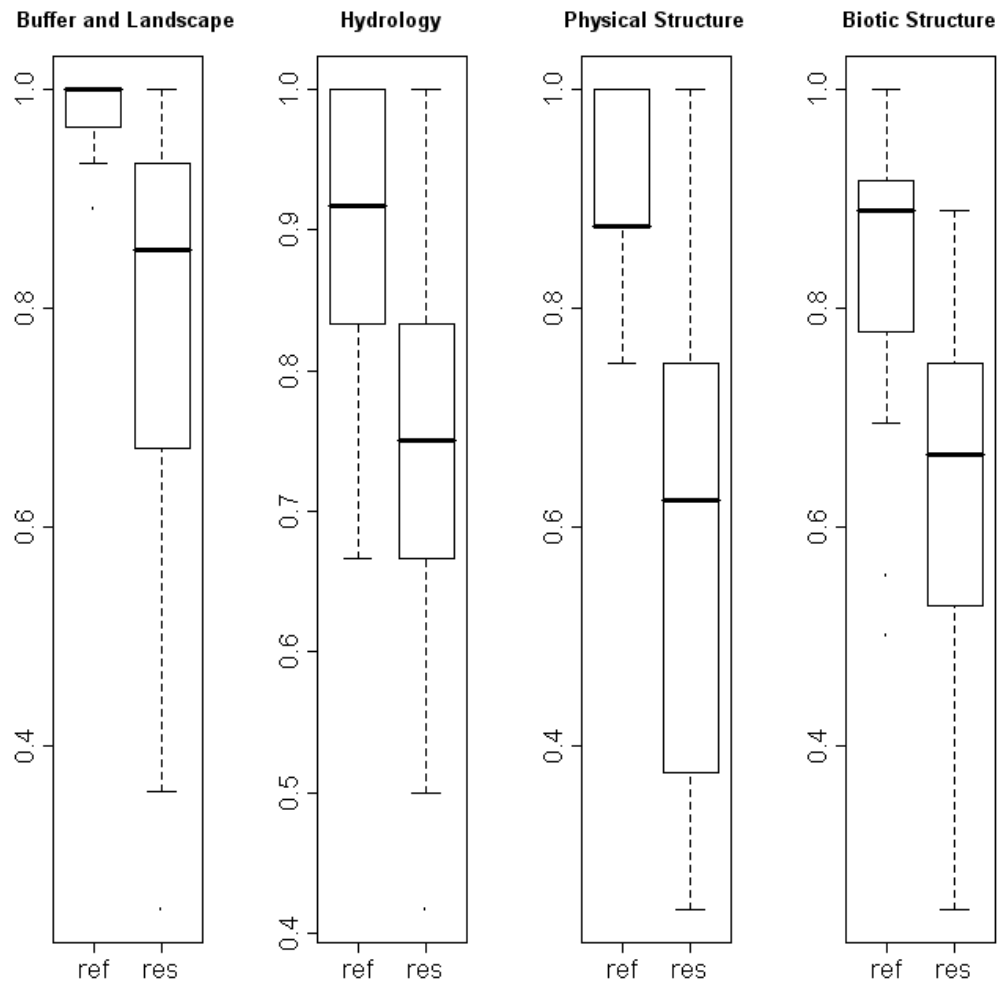
There was no significant correlation between age of the project and overall CRAM score ( $df = 37$ ,  $p = 0.65$ ). Figure 3 shows the random scatter of age of project vs. CRAM score.



**Figure 3. Scatterplot of Age of Project vs. CRAM Score**

Mean attribute and metric scores were also significantly higher for reference sites than for restoration sites ( $p < 0.001$ ,  $t = 2.9-7.1$ ,  $df = 65$ , for all except landscape

connectivity and hydrologic connectivity which had  $p < 0.05$ ). Figure 4 shows the distribution of attributes, where the boxes approximate quartiles, and the lines or “whiskers” extending away from the boxes go to the most extreme data point that falls within a distance of one and a half times the box size (Dalgaard 2002).

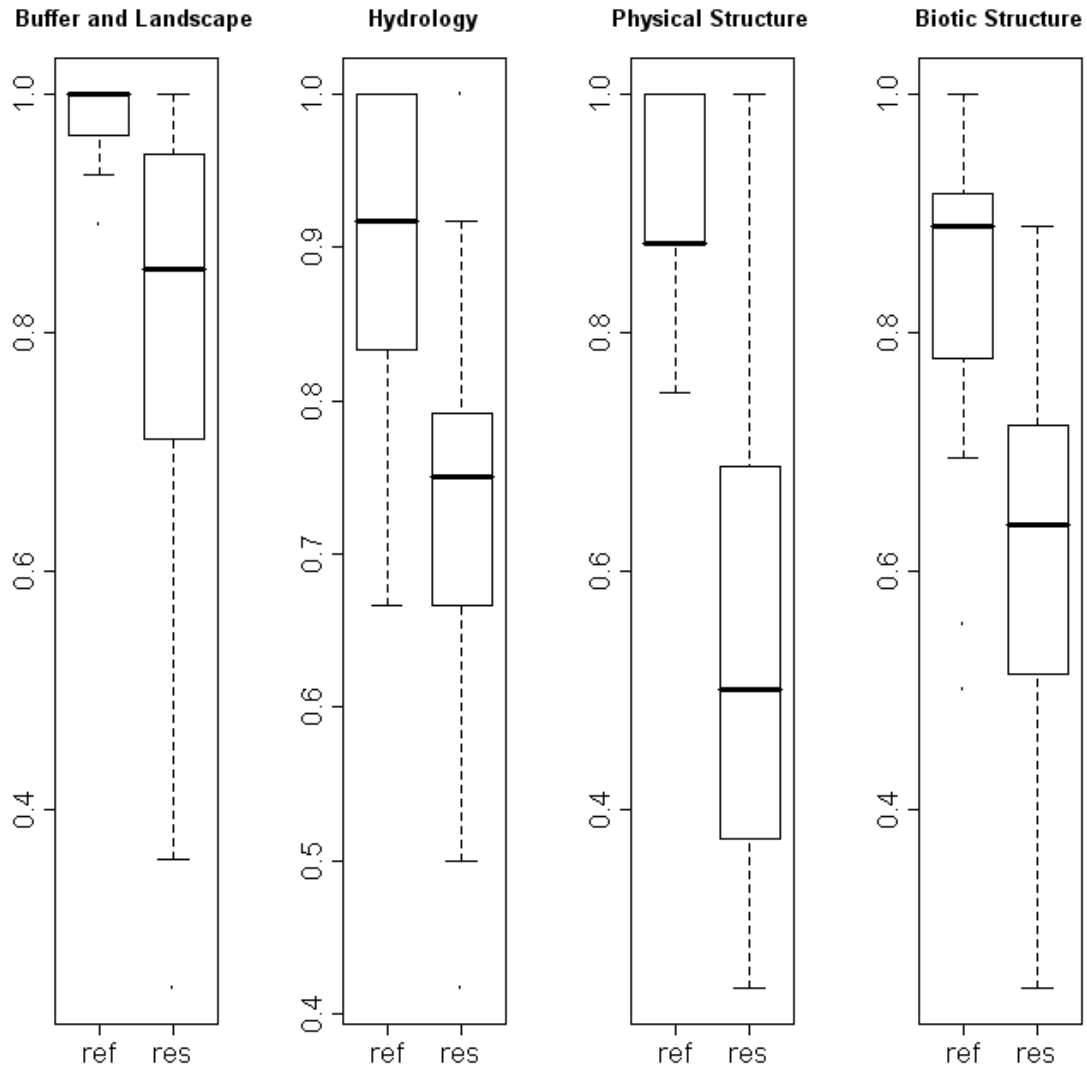


**Figure 4. Boxplot showing distributions of attributes (ref = reference, res = restored)**

The distribution of restoration sites is highly variable, but the upper quartiles for most attributes fall well below the reference site lower quartile. This pattern is less clear for the hydrology attribute, where there is more overlap between restoration and reference sites (Figure 4). Without the fish passage projects, there is a bigger discrepancy



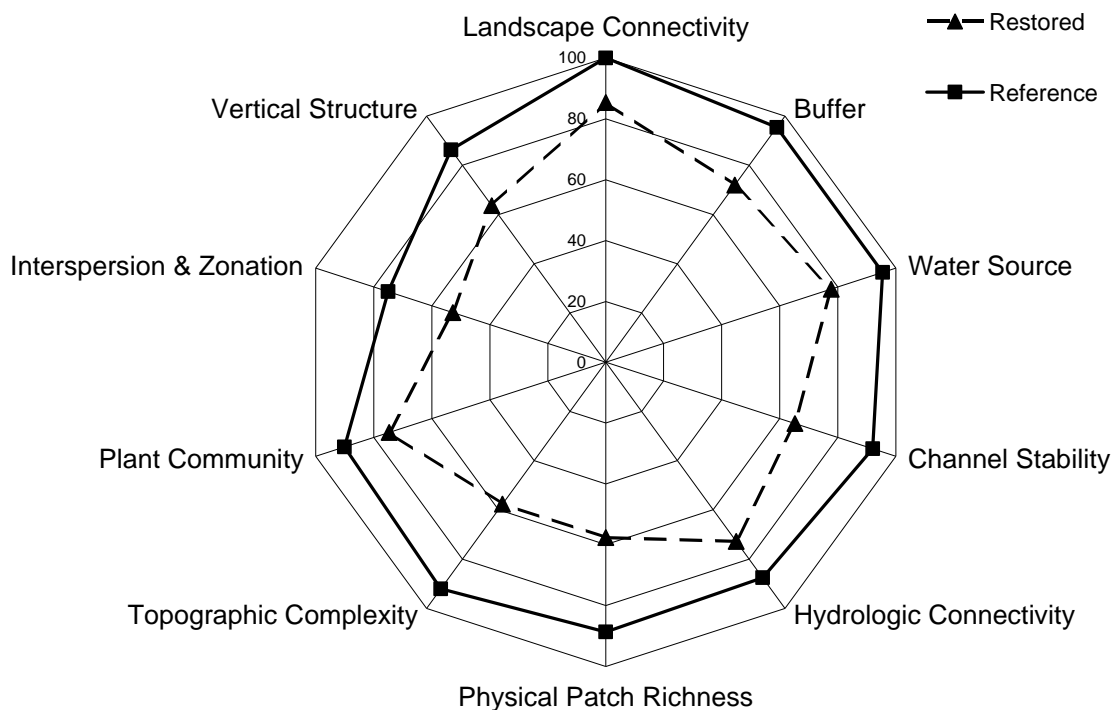
between reference and restored sites in all of the attributes except buffer and landscape context, where restoration sites are closer to reference condition (Figure 5).



**Figure 5. Boxplot showing distributions of attributes without fish passage projects (ref = reference, res = restored)**

Each spoke of the wheel in Figure 6 represents one metric, and the distance from the center indicates the mean score for reference or restored sites in that metric. Figure 6 demonstrates the difference in means at the metric level between reference and restoration sites. The largest difference in means was in the two physical structure

metrics; physical patch richness (31%) and topographic complexity (34%). channel stability also had a relatively high discrepancy (27%) between reference and restored sites (Figure 6). The spider plot without fish passage projects was visually indistinguishable from the original plot.



**Figure 6. Spider plot showing reference and restored means for each metric**

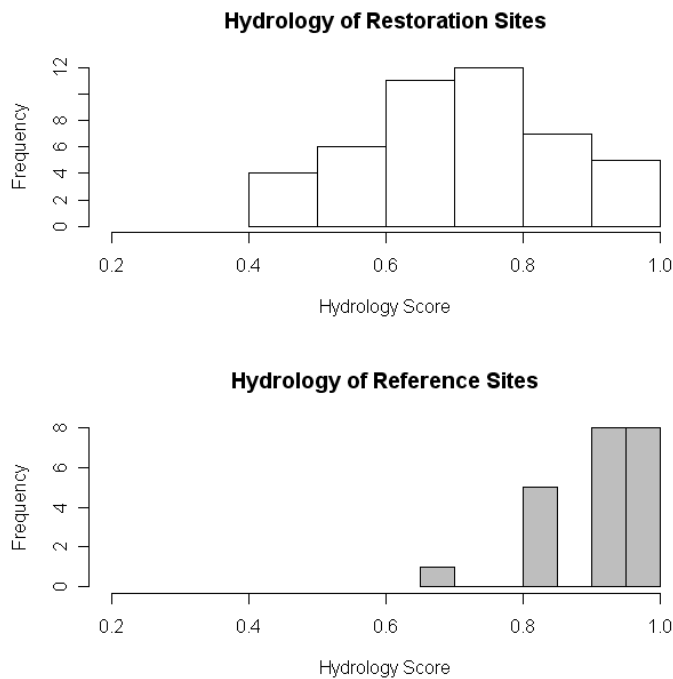
The MANOVA analysis was strongly significant at both the attribute level ( $p < 0.001$ ,  $F_{1,4} > 22$ ) and metric level ( $p < 0.001$ ,  $F_{1,10} > 10$ ).

The discriminant analysis indicates which factors contribute most to the difference between the restored and reference sites. Discriminant scores are expressed as absolute value, and the magnitude of the score indicates the relative influence of a particular variable on the separation between reference and restoration sites. The approximate  $F_{1,4}$  of 22.98 (based on Wilks' lambda) was highly significant ( $p < 0.001$ ), which means that there is a reliable separation of groups based on the four attributes

(Tabachnik and Fidell 2001). In the analysis of CRAM Attributes, hydrology (**bold**) is the most important variable in separating restoration sites from reference sites (Table 2). Figure 7 shows the distribution of hydrology scores for restoration and reference sites. Biotic structure had the second highest discrimination ability, while landscape context and physical structure were not as prominent (Table 2).

**Table 2. Discriminant scores (absolute value) at attribute level (bold text indicates highest discriminant score)**

| Attribute          | Discriminant Score |
|--------------------|--------------------|
| Landscape Context  | 0.027              |
| <b>Hydrology</b>   | <b>0.055</b>       |
| Physical Structure | 0.017              |
| Biotic Structure   | 0.042              |



**Figure 7. Distribution of hydrology scores for restoration and reference sites**

Metrics are the basic units that compose a CRAM assessment, and each attribute is a combination of two or more metrics. Channel stability was the strongest discriminating variable at the metric level, followed by the plant community, buffer, and vertical structure metrics (Table 3). When the analysis was repeated with fish passage projects excluded ( $N_{\text{restored}} = 31$ ,  $N_{\text{reference}} = 22$ ), the buffer metric was the strongest determinant, followed by channel stability and vertical structure.

**Table 3. Discriminant scores (absolute value) at metric level (bold text indicates highest discriminant score)**

| Metric                     | Discriminant Score | Discriminant Score (w/out fish passage) | Discriminant Score (incl. plant sub-metrics) |
|----------------------------|--------------------|---|--|
| Landscape Connectivity     | 0.010              | 0.001                                   | 0.009  |
| Buffer                     | 0.017              | <b>0.031</b>                            | 0.019  |
| Water Source               | 0.008              | 0.015                                   | 0.008  |
| Channel Stability          | <b>0.041</b>       | 0.029                                   | <b>0.042</b>                                 |
| Hydrologic Connectivity    | 0.008              | 0.009                                   | 0.006  |
| Physical Patch Richness    | 0.008              | 0.007                                   | 0.011  |
| Topographic Complexity     | 0.011              | 0.013                                   | 0.014  |
| Plant Community            | 0.024              | 0.013                                   |  |
| Plant Layers               |                    |   | 0.006  |
| # of Species               |                    |   | 0.006  |
| % Invasion                 |                    |   | 0.004  |
| Interspersion and Zonation | 0.010              | 0.005                                   | 0.008  |
| Vertical Structure         | 0.017              | 0.020                                   | 0.020  |

A third discriminant analysis at the metric level included each of the plant sub-metrics individually, and this yielded similar results to the original analysis. Channel stability was the most important metric, followed by vertical structure and buffer. None of the plant sub-metrics taken individually was a strong discriminator (Table 3). All three of the variations on the discriminant analysis were highly significant ( $p < 0.001$ ).

## DISCUSSION

Differences between reference and restored sites show the deficiencies of the restored sites. Reference sites represent the best attainable condition for restoration projects in the Central Coast region, and can be used as a measuring stick to assess the performance of restoration sites. Adaptive management and science-based restoration require evaluating past projects and communicating lessons learned. Future efforts will benefit from analyzing problems with past projects. Restoration projects in this study had significantly lower scores than reference sites for the overall CRAM assessment and for every single attribute and metric. It is clear that the majority of restoration projects are not attaining reference condition, and a more detailed investigation of specific attributes and metrics will show where and how restoration practices can be improved.

The hydrology attribute was the main discriminator between reference and restored sites. The disparity in hydrology indicates that restoration projects are not recreating natural hydrologic functions. A functional hydrologic regime includes natural sources of water, equilibrium channel conditions, and access to the adjacent floodplain (Rosgen 2006). These conditions can be difficult to recreate, especially in urban systems that are constrained by infrastructure (Kondolf 1996). Hydrology is a fundamental driver of river ecosystems; it affects the nature of the plant community and the physical habitat structures in a river.

A study of the Sacramento and Cosumnes River floodplains showed that flood disturbance was an important factor in sustaining heterogeneous habitat and diverse

riparian species (Viers et al. 2005). Elderd (2005) found that altering flow regimes through damming or impoundment impacts plant performance, and that bankfull or greater flow events are necessary to maintain diverse plant communities through resetting disturbance rates. Restoring sustainable hydrologic processes that create floodplain topography promotes variability in physical structure (Florsheim and Mount 2002). Restoration projects often attempt to enhance dynamic equilibrium, although this may not be socially acceptable if hydrologic dynamism is a threat to infrastructure (Shields et al. 2003b). There can be tension between ecological objectives and flood control or bank stabilization interests, however the risks can be reduced by phasing restoration, employing adaptive management, or using control structures such as sediment basins (Shields et al. 2003b). Reference sites for this study were generally in watersheds with natural flow regimes, whereas many of the restoration projects were in urban or agricultural areas where hydrologic restrictions are more prevalent. Sound restoration practices can ameliorate the effects of anthropogenic modifications on stream systems. It is possible to work within present constraints to achieve improvements in habitat and also meet human needs. One example is termed “soft engineering,” where bank stabilization structures are combined with riparian plantings (Kondolf 1996). These practices were seen in one project in Scott’s Creek on the Swanton Pacific Ranch, where a cribwall made of logs was placed upstream of a railroad crossing to stabilize the bank, and living willow plugs were placed into the structure. These provide wildlife habitat and a source of allochthonous material to the stream, while allowing for human use in stabilizing the bank.

In their study of mitigation projects in California, Ambrose et al. (2006) found that mitigation sites had a median hydrology score that was 69% of the reference median for that attribute (63 for mitigation projects vs. 91 for reference sites). Their methodology to define reference condition was similar to this study, so the results are comparable. The median hydrology attribute score for restoration projects was 82% of the reference median (75 for restoration projects vs. 92 for reference sites). The population of restoration projects that was assessed for this study was on average closer to reference

condition than the mitigation projects in the Ambrose et al. (2006) study. Although restoration projects do not reach reference condition for the hydrology attribute, they are at least in better condition than statewide mitigation projects. There is considerable variation in the dedication and proficiency of mitigation implementers, and the Ambrose study found that many projects were never actually implemented or were poorly executed (Ambrose et al. 2006). State-funded restoration projects appear to be more effective in achieving good stream condition.

At the individual metric level, channel stability was the strongest discriminator. This was the underlying factor driving the discrimination of the overall hydrology attribute. Channel stability evaluates the equilibrium of the channel system; if it is stable, eroding or aggrading. Natural channels are in equilibrium with the amount of water and sediment being delivered from their watershed, but perturbations in the system can cause a stream to fill in or degrade in an attempt to return to equilibrium (Rosgen 2006). Restoration projects often try to reverse these processes by stabilizing banks with structures (Roni et al. 2002), removing excess sediment, or creating detention basins to collect sediment (NRC 1992). However, if these activities do not address the conditions in the watershed that are causing disequilibrium, they are likely to fail (Stromberg 2001). For example, riparian plantings often fail if the natural flow of water and sediment has not been restored, and the underlying conditions that caused the original decline are not addressed (Stromberg 2001). Both the discriminant analysis and the comparison of means pointed to channel stability as the metric where restoration projects are deficient. The discrepancy calls for the need for restoration projects to address the watershed scale and broaden the view beyond a single stream reach. When practitioners use a watershed scale approach, they understand the ecosystem processes that affect a stream site and the stresses that must be addressed (Bohn and Kershner 2002). Where possible, the entire watershed upstream of a restoration project should be investigated to identify conditions or events affecting the flow regime and sediment load, such as dam construction or sources of excess sediment (Kondolf and Larson 1995). Restoration provides an exceptional opportunity to influence habitat across large spatial scales (Bond and Lake

2003). Funding constraints limit practitioners ability to broaden the scope of restoration planning, but coordination and comprehensive visioning can extend available resources.

The CRAM method evaluates stream channel stability by looking at indicators of aggradation or degradation, and sites with artificially hardened banks (e.g. rip-rap or concretization of the channel) are scored lower (Collins et al. 2007). Many restoration projects have rip-rap or other bank stabilization structures, which could be one reason for the gap between restoration and reference sites in the channel stability metric. Fish passage projects in particular often have hardened structures such as cement fish ladders or rip-rap to protect banks adjacent to culverts (Roni et al. 2005). Fish passage projects usually focus on a specific barrier to anadromous fish migration but do not address conditions beyond that. When these projects were removed from the analysis, the buffer metric had the highest discriminant score, followed by channel stability (Table 3). This indicates that channel stability is particularly problematic for fish passage projects, but buffer is a bigger issue for other types of restoration projects. That is not to say that channel stability is not a problem for all types of restoration projects, but that including fish passage projects in the study may have skewed the results to emphasize this metric. However, even without fish passage improvement projects, channel stability is still targeted as an area of concern for restoration projects, but it is secondary to the buffer metric.

The importance of riparian buffer zones is widely recognized (Shearer and Xiang 2007). A buffer zone mediates anthropogenic stresses and provides habitat and movement corridors (Welsch 1991). Buffer emerged as an issue for stream restoration projects in the central coast when fish passage projects were not included (Table 3). The buffer metric is a combination of sub-metrics that score the buffer coverage, the buffer width, and the condition of the buffer (Table 1). At the outset of this study I expected that the buffer metric would be an important discriminating factor between restored and reference sites, but this was not immediately apparent in the discriminant analysis. Restoration site scores were significantly lower than reference site scores for the buffer metric ( $p < 0.001$ ), but this metric was not at first targeted by the discriminant analysis. Many of the fish passage



barrier removal projects assessed were in relatively undisturbed areas with intact forest buffers. These areas provide potential spawning habitat for anadromous fish, and as such must support adequate functions for these sensitive species. In many cases the only problem was the presence of a barrier to passage. For example, a project on Wilder Creek in Wilder Ranch State Park north of Santa Cruz, California removed a concrete spillway that was a barrier to fish. This creek is in a state park and has an intact buffer zone.

Another project on Mountain Charlie Gulch in the Santa Cruz Mountains improved fish habitat in an area that is heavily forested and closed to the public. This area is relatively free of anthropogenic stress, aside from the legacy of intensive logging that created the barriers to fish passage. Many of the fish passage projects had intact buffers, but with these projects removed from the analysis, the buffer metric was the top discriminating variable (Table 3). Other types of stream restoration projects are often more restricted by adjacent land use, particularly in urban or agricultural systems. Results indicate that restoration projects rarely have adequate buffer zones, particularly in projects not aimed at fish passage improvement. Other types of projects include bank stabilization, invasive species removal, water quality improvement, physical and hydrogeomorphological restoration.

The initial discriminant analysis identified the plant community metric as an area of concern. This metric is actually composed of three sub-metrics; number of plant layers, number of co-dominant species, and percent invasion. To determine which of these sub-metrics was driving the difference between restoration and reference sites, the discriminant analysis was re-calculated with each of the plant community sub-metrics included as a distinct variable. None of the sub-metrics was a strong discriminator individually, although the number of height classes and species were stronger than the percent invasion metric (Table 3). This indicates that there is not a specific problem with invasion by exotic species or diversity of species or height classes. The combination of plant community aspects is responsible for the difference between reference and restored sites. Restoration projects that focus exclusively on invasive species removal sometimes ignore the importance of establishing diverse native plant communities. Results point to

the need to address the entire plant community and not just a single aspect such as invasive species.

On average, the biggest gap between restoration projects and reference condition was in the physical structure metrics, physical patch richness and topographic complexity. Patch richness is a checklist of habitat structures that might be expected in a healthy, functioning stream, and the topographic complexity metric is a measure of diversity of elevation and moisture gradients that foster habitat and hydrologic complexity (Collins et al. 2007). Topographic complexity is closely related to fully functioning hydrology, because water and sediment moving down the system shape the channel and create secondary channels and surface roughness (Rosgen 2006). Anthropogenic constraints on rivers sometimes prevent them from achieving optimal functionality, and many restoration projects are in urban systems where they are subject to excessive human influence. However, it is possible to improve physical habitat within the constraints of urban systems (Larson et al. 2001). A study of urban stream restoration in the Puget Sound Lowland of Washington state found that in-stream log placement improved physical habitat by reducing spacing between pools relative to pre-project conditions (Larson et al. 2001)

Future restoration efforts should provide adequate buffer, and aim to restore fully functioning hydrology and physical diversity. This recommendation applies to both land managers who implement restoration projects and agencies and programs that fund restoration. Stabilizing channels without compromising ecological integrity needs to be a priority for stream managers (Kondolf 1996). Restoration projects should address the watershed scale in order to understand the ecosystem processes that affect a particular stream reach, and improve hydrologic and physical conditions (Bohn and Kershner 2002). Where possible, riparian buffer zones must be maintained to control invasive weed vectors and other anthropogenic stresses on stream systems. It is important to acknowledge that restoration practitioners must work within the constraints of the system they are restoring. In urban areas it may not be possible to provide a wide buffer, but ensuring high quality buffer where present is possible through vegetation management.

Likewise, levees often constrict the lateral extent of rivers and reduce access to former floodplains, and in these areas it may not be possible to restore complete hydrologic functions and physical structure. Improvements within these constraints are still possible, such as enhancing structural habitat (Larson et al. 2001). Pushing the edge of the boundary is crucial to accomplish advances in restoration science and practice.

The process undertaken in this project yielded important lessons. Compiling the database of projects, attempting to contact implementers, and standardizing project information presented significant challenges. Information about specific restoration projects is not always readily available, and certainly not in a standard format. Palmer et al. (2005) included in their definition of successful restoration a pre- and post-project assessment and public availability of that data. Very few of the projects included in this study had any pre- and post-project assessment. About three-quarters of the projects not on private land had publicly accessible data. The paucity of monitoring on river restoration projects and current piecemeal monitoring methods reduces their benefit to restoration science (Bash and Ryan 2002). Few restoration projects include evaluation of success, which limits knowledge transfer of lessons learned to enhance future projects (Caruso 2006). Almost none of the restoration projects in this study performed a self-evaluation, and if they did it was usually buried in a grant report and not publicly accessible. Improvement in the standardization and public availability of information about restoration projects is crucial to future adaptive management.

This study shows how CRAM can be used to monitor and assess river restoration projects to improve future efforts. The timeline constrained this study to post-project assessments, but future projects could use CRAM to perform pre- and post-project assessments and evaluate trends in system enhancement. Many authors have explored methods to evaluate restoration success. However, techniques are not always rapid and therefore place a greater burden on already limited budgets. For example, Kondolf and Micheli (1995) suggest measurement of geomorphic variables along with hydrologic and ecological variables on the same transects. If unlimited funding were available, this could be easily accomplished, but in reality monitoring budgets are often constrained. CRAM

provides a cost-effective yet comprehensive tool to evaluate projects. The Society for Ecological Restoration suggests in their Primer that the best approach to monitor projects is to select a coherent set of traits that describe an ecosystem fully yet succinctly (SER 2004). This is exactly what CRAM does for California aquatic ecosystems (Stein et al. 2007). CRAM successfully identified key areas for improvement in future restoration projects in this study. Although objectives and methods for restoration are myriad, CRAM offers a calibrated and standardized method to assess changes in condition (Stein et al. 2007). It can be used to implement uniform monitoring across restoration projects and improve restoration quality. The next steps are to build a dataset of pre- and post-restoration CRAM assessments, and to gather support for standardized monitoring among restoration practitioners and funding agencies.

## **CHAPTER 3**

### **REFLECTIONS AND FUTURE WORK**

This study has stimulated questions and reflections on the use of CRAM and the concept of reference condition. This chapter delves into these issues and describes potential future work that may result.

For further reference, summary statistics are located in Appendix C. Appendix D provides latitude and longitude coordinates for each of the restoration projects and reference sites, except for sites that were on private property. A representative sample of photographs from the sites is found in Appendix E.

Characterizing reference condition for the Central Coast was a challenging task. There is quite a range of stream conditions in the region. Reference sites represent the current best attainable condition, but one question of concern is the long-term condition of reference sites. CRAM provides a snapshot of present status, and some of the metrics look for indicators of long-term trends, but a single assessment does not measure changing conditions over time. This is a concern particularly because channel stability was such an important metric in the analysis. This metric looks for trends in the equilibrium condition of the channel, and indicators of disequilibrium such as scoured channel beds or splays of fresh sediment (Collins et al. 2007). Results of this study indicate that reference sites are closer to equilibrium than restoration sites. However, it is possible that these conditions will change over time. If the reference sites were re-assessed, would they continue to maintain equilibrium? They could be impacted by natural disturbances such as fires or floods. Yearly fluctuations in rainfall and climatic patterns can change the condition of streams over time. There also may be an effect of seasonality on reference condition. It would be interesting to assess reference sites multiple times during different periods of the growing season.

Expanding the reference site pool would assist in characterizing reference condition. Reference sites for this study came from a mix of high and low gradient sites, and future work on the reference network should continue to sample a wide range of habitats and geomorphic conditions. One area where additional reference sites are needed is in the Morro Bay watershed, and also in the eastern part of the Central Coast. These areas had few if any reference sites in this study, so finding additions to the reference network in this part of the region would be beneficial.

Some restoration practitioners may feel that aiming for reference condition is an unattainable goal. While it would be difficult for most projects to reach reference condition through restoration activities, I believe that it is important to have something to strive towards. Reference condition represents a template of a healthy, functioning ecosystem. However, in systems that are highly impacted by agriculture or urbanization, they are not going to return to some historical condition. There may be value in choosing reference sites that represent the best attainable condition within a certain land-use type such as developed urban land or row-crop agriculture. These would be the best sites that are found in the particular land-use type. This was done in a recent study of the Central Valley that used reference sites to create an Index of Biological Integrity (Rehn 2008). There are no pristine stream reaches in the Central Valley region, and their study used landscape variables to select sites that are the best to be found within the region. However, there is a danger to this approach, because it allows highly impacted sites to be characterized as reference sites. If this approach was used to set goals for restoration, this would be admitting defeat before a restoration project is even started.

This study demonstrates the utility of the reference site approach in evaluating restoration projects. Another approach assesses restoration projects based on a comparison to an un-restored reach, using this as a proxy for pre-restored condition (Maas-Baldwin 2008). The two approaches are complimentary. The comparison to an un-restored reach shows specific improvements in a particular system, while the reference site approach evaluates progress toward the goal of reference condition.

CRAM has gone through developmental stages since its inception over ten years ago, and is now coming into wider use as agencies adopt it and require its use by staff and consultants. The next obvious step after this project is to assess projects before and after restoration has been performed. This has begun with the Manabe project in Watsonville, which restored an agricultural field and re-graded it to support wetland habitat. A few projects in the Moro Cojo watershed have been assessed pre-restoration, one enhanced wetland in a freshwater depression system and another site where rangeland was fenced off from the estuary. These assessments show initial improvement, but more time would allow for plant communities to be established, particularly at the Manabe site. When more projects can be assessed both pre- and post-restoration, we will gain a clearer picture of how CRAM reflects these beneficial manipulations to the landscape.

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## **APPENDICES**

### **APPENDIX A**

#### **PROJECT TRACKING DATABASES**

- Natural Resource Projects Inventory (University of California at Davis)  
<http://www.ice.ucdavis.edu/nrpi/>
- National River Restoration Science Synthesis (United States Geological Survey)  
<http://nrrss.nbii.gov/>
- Central Coast Regional Water Quality Control Board
- Habitat Conservation Fund (State Parks) <http://www.habitatconservationfund.org/>
- California Habitat Restoration Project Database (California Department of Fish and Game)  
<http://www.calfish.org/ProgramsandProjects/RestorationProjects/tabid/99/Default.asp>

x



## **APPENDIX B**

### **R STATISTICAL COMPUTING CODE**

```
# file with all metrics and attributes
# Attributes: buffland, hydro, phys, bio
# Metrics: landconn, buff, h2source, hper, hconn, patch, topo, plant, inter, vert
# "group" for reference vs. restored

library(car)
library(MASS)

test<-read.csv("C:\\Documents and Settings\\Cara\\My Documents\\CRAM\\Restoration
CRAM\\Analysis\\2008_0711_MASTER.csv")
attach(test)

lc_mod<-lm(landconn~group)
lc_aov<-anova(lc_mod)
plot(lc_mod)
summary(lc_aov, test="Wilks")
# qq plot looks okay, needs transformation
hist(landconn)
#square root and log transformations:
lcmod2<-lm(lcsqr~group)
plot(lcmod2)
lcmod3<-lm(lclog~group)
plot(lcmod3)
lcmod4<-lm(lcarc~group)
plot(lcmod4)
hist(lclog)

buff_mod<-lm(buff~group)
buff_aov<-anova(buff_mod)
```

```
plot(buff_mod)
hist(buff)
# needs transformation
buffmod2<-lm(buffsq~group)
plot(buffmod2)
buffmod3<-lm(bufflog~group)
plot(buffmod3)
buffmod4<-lm(buffarc~group)
plot(buffmod4)
```

```
h2_mod<-lm(h2source~group)
h2_aov<-anova(h2_mod)
plot(h2_mod)
# qq plot crosses through line
h2mod2<-lm(h2sq~group)
plot(h2mod2)
h2mod3<-lm(h2log~group)
plot(h2mod3)
h2mod4<-lm(h2arc~group)
plot(h2mod4)
```

```
hpermod<-lm(hper~group)
plot(hpermod)
# that one looks okay, may not need transformation
hpmod2<-lm(hpersqr~group)
plot(hpmod2)
hpmod3<- lm(hperlog~group)
plot(hpmod3)
hist(hper)
```

```
hpmod4<-lm(hperacr~group)
plot(hpmod4)
```

```
hconnmod<-lm(hconn~group)
plot(hconnmod)
hcm2mod<-lm(hconnsq~group)
plot(hcm2mod)
hcm3mod<-lm(hconnlog~group)
plot(hcm3mod)
hcm4mod<-lm(hconnarc~group)
plot(hcm4mod)
# looks okay, may not need transformation
```

```
patchmod<-lm(patch~group)
plot(patchmod)
pmod2<-lm(patchsq~group)
plot(pmod2)
pmod3<-lm(patchlog~group)
plot(pmod3)
pmod4<-lm(patcharc~group)
plot(pmod4)
# looks almost the same w/ square root transformation, looks normal anyway
```

```
topomod<-lm(topo~group)
plot(topomod)
tmod2<-lm(toposq~group)
plot(tmod2)
tmod3<-lm(topolog~group)
plot(tmod3)
tmod4<-lm(topoarc~group)
plot(tmod4)
```

```
plantmod<-lm(plant~group)
plot(plantmod)
plantmod2<-lm(plantsqr~group)
plot(plantmod2)
plantmod3<-lm(plantlog~group)
plot(plantmod3)
plantmod4<-lm(plantarc~group)
plot(plantmod4)
```

```
intermod<-lm(inter~group)
plot(intermod)
imod2<-lm(intersqr~group)
plot(imod2)
imod3<-lm(interlog~group)
plot(imod3)
imod4<-lm(interarc~group)
plot(imod4)
```

```
vertmod<-lm(vert~group)
plot(vertmod)
vmod2<-lm(vertsqr~group)
plot(vmod2)
vmod3<-lm(vertlog~group)
plot(vmod3)
vmod4<- lm(vertarc~group)
plot(vmod4)
hist(vert)
hist(vertarc)
```

# Discriminant Analysis with some transformed variables, or with all original:

```
lda_og<-lda(group~landconn+buff+h2source+hper+hconn+patch+ topo + plant + inter +
vert)
lda_og
lda_trans<-
lda(group~lclog+buffarc+h2arc+hper+hconn+patch+topoarc+plantarc+interarc+vert)
lda_trans
lda_trans2<-
lda(group~lclog+buffarc+h2arc+hper+hconn+patch+topoarc+plantarc+interarc+vertarc)
lda_trans2
lda_trans3<-
lda(group~lclog+buffarc+h2arc+hperacr+hconn+patch+topoarc+plantarc+interarc+vertarc)
lda_trans3
lda_trans4<-
lda(group~lclog+buffarc+h2arc+hperacr+hconnarc+patch+topoarc+plantarc+interarc+vertarc
)
lda_trans4
lda_trans5<-
lda(group~lclog+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc+vert
arc)
lda_trans5
lda_trans6<-
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc+vert
arc)
lda_trans6
lda_trans7<-lda(group~lcarc+h2arc+hperacr+hconnarc+patcharc+topoarc+interarc+vertarc)
lda_trans7

# eigenvalue for lda_trans7
```

```
lda_trans7$svd
```

```
# DA leaving one variable out (sensitivity analysis)
```

```
lda_sens1<-
```

```
lda(group~buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc+vertarc)
```

```
lda_sens1
```

```
lda_sens2<-
```

```
lda(group~lcarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc+vertarc)
```

```
lda_sens2
```

```
lda_sens3<-
```

```
lda(group~lcarc+buffarc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc+vertarc)
```

```
lda_sens3
```

```
lda_sens4<-
```

```
lda(group~lcarc+buffarc+h2arc+hconnarc+patcharc+topoarc+plantarc+interarc+vertarc)
```

```
lda_sens4
```

```
lda_sens5<-
```

```
lda(group~lcarc+buffarc+h2arc+hperacr+patcharc+topoarc+plantarc+interarc+vertarc)
```

```
lda_sens5
```

```
lda_sens6<-
```

```
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+topoarc+plantarc+interarc+vertarc)
```

```
lda_sens6
```

```
lda_sens7<-
```

```
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+plantarc+interarc+vertarc)
```

```
lda_sens7
```

```
lda_sens8<-
```

```
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+interarc+vertarc)
```

```
lda_sens8
```

```
lda_sens9<-
```

```
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+vertarc)
```

```
lda_sens9
```

```

lda_sens0<-
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc)
lda_sens0
# jackkified prediction:
as.factor(group)
lda_jack<-
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+plantarc+interarc+vert
arc, CV = TRUE)
ct<- table(group, lda_jack$class)
diag(prop.table(ct,1))
#total percent correct
sum(diag(prop.table(ct)))
#scatter plot
plot(fit2)
# Discriminant Analysis on attributes

lda_att<-lda(group~buffland+hydro+phys+bio)
lda_att
lda_att2<-lda(group~blarc+hydro+phys+bioarc)
lda_att2
lda_att3<-lda(group~blarc+hydroarc+physarc+bioarc)
lda_att3

# Test Attributes:

blmod<-lm(buffland~group)
plot(blmod)
blmod2<-lm(blsqr~group)
plot(blmod2)
blmod3<-lm(bllog~group)
plot(blmod3)

```



```
blmod4<- lm(blarc~group)
plot(blmod4)
```

```
hydromod<-lm(hydro~group)
plot(hydromod)
hymod2<-lm(hydrosqr~group)
plot(hymod2)
hymod3<-lm(hydrolog~group)
plot(hymod3)
hymod4<-lm(hydroarc~group)
plot(hymod4)
```

```
physmod<-lm(phys~group)
plot(physmod)
physmod2<-lm(physsqr~group)
plot(physmod2)
physmod3<-lm(physlog~group)
plot(physmod3)
physmod4<-lm(physarc~group)
plot(physmod4)
```

```
biomod<-lm(bio~group)
plot(biomod)
biomod2<-lm(biosqr~group)
plot(biomod2)
biomod3<- lm(biolog~group)
plot(biomod3)
biomod4<-lm(bioarc~group)
plot(biomod4)
```

```
# the arcsin sq root seems to do the best for biotic structure
```

# homogeneity of variances tests:

```
bartlett.test(landconn~group)
```

```
bartlett.test(lcsqr~group)
```

```
bartlett.test(lclog~group)
```

```
bartlett.test(lcarc~group)
```

# exactly the same results with trans... highly significant test, so variances not equal?

```
bartlett.test(buff~group)
```

```
fligner.test(buff~group)
```

```
bartlett.test(h2source~group)
```

```
bartlett.test(hper~group)
```

```
    bartlett.test(hconn~group)
```

```
bartlett.test(patch~group)
```

```
bartlett.test(topo~group)
```

```
bartlett.test(plant~group)
```

```
bartlett.test(inter~group)
```

```
bartlett.test(vert~group)
```

# Levene's test is more robust for non-normality

```
levene.test(landconn, group)
```

```
levene.test(buff, group)
```

```
    levene.test(h2source,group)
```

```
levene.test(hper,group)
```

```
    levene.test(hconn,group)
```

```
levene.test(patch,group)
```

```
levene.test(topo,group)
```

```
levene.test(plant,group)
```

```
levene.test(inter,group)
```

```
levene.test(vert,group)
```

# with  $\alpha = 0.01$  all tests have  $p\text{-value} > \alpha$  except landscape connectivity, buffer and water source

# test buffer and water source with transformations:

```

levene.test(lcsqr, group)
levene.test(lclog, group)
levene.test(lcarc, group)
levene.test(buffsq,group)
levene.test(bufflog,group)
levene.test(buffarc,group)
levene.test(h2sq,group)
levene.test(h2log,group)
levene.test(h2arc,group)
# the arcsin square root transformation results in non-significant test for
# buffer and water source (other 2 transformations don't help)

# levene's test on attributes:
levene.test(buffland,group)
levene.test(hydro,group)
levene.test(phys,group)
levene.test(bio,group)
# hydro and bio pass w/out trans, try trans on buffland and physical:
levene.test(blsqr,group)
levene.test(bllog,group)
levene.test(blarc,group)
levene.test(physsqr,group)
levene.test(physlog,group)
levene.test(physarc,group)
# Physical structure with the arcsin sq root transformation passes the test, but not Buffer and
Landscape Context

# MANOVA on metrics and attributes:
# Attributes:
att.man<-manova(cbind(buffland, hydro, phys, bio)~group)
summary(att.man, test = "Hotelling")

```

```
summary(att.man, test = "Pillai")
summary(att.man, test = "Wilks")
summary(att.man, test = "Roy")
```

# manova with transformations:

```
att.man2<-manova(cbind(blarc, hydro, physarc, bioarc)~group)
summary(att.man2, test = "Hotelling")
summary(att.man2, test = "Pillai")
summary(att.man2, test = "Wilks")
summary(att.man2, test = "Roy")
att.man3<-manova(cbind(blarc, hydroarc, physarc, bioarc)~group)
summary(att.man3, test = "Wilks")
```

# manova on metrics:

```
met.man<-manova(cbind(landconn, buff, h2source, hper, hconn, patch, topo, plant, inter,
vert)~group)
summary(met.man, test = "Hotelling")
summary(met.man, test = "Pillai")
summary(met.man, test = "Wilks")
summary(met.man, test = "Roy")
```

```
met.man2<-
manova(cbind(lclog,buffarc,h2arc,hper,hconn,patch,topoarc,plantarc,interarc,vertarc)~group)
summary(met.man2, test = "Hotelling")
summary(met.man2, test = "Pillai")
summary(met.man2, test = "Wilks")
summary(met.man2, test = "Roy")
met.man3<-
manova(cbind(lclog,buffarc,hper,hconn,patch,topoarc,plantarc,interarc,vertarc)~group)
summary(met.man3, test = "Wilks")
```

```
met.man4<-manova(cbind(lclog,buffarc,h2arc,hper,hconn,patch,topoarc,plantarc,interarc,
vertarc)~group)
```

```
summary(met.man4, test = "Wilks")
```

```
met.man5<- manova(cbind(lcarc, buffarc, h2arc, hperacr, hconnarc, patcharc, topoarc,
plantarc, interarc, vertarc)~group)
```

```
summary(met.man5, test = "Wilks")
```

```
#Graphics
```

```
Reference <-CRAM[group == "ref"]
```

```
Restoration <-CRAM[group == "res"]
```

```
par(mfrow=c(2,1))
```

```
hist(Restoration, main = "Restoration Sites", xlim = c(30,100), ylim = c(0,12), xlab =
"CRAM Index Score", col = "white")
```

```
hist(Reference, main = "Reference Sites", xlim = c(30,100), ylim = c(0,12), xlab = "CRAM
Index Score", col = "grey")
```

```
Reference_BufferLandscape <-buffland[group == "ref"]
```

```
Restoration_BufferLandscape <-buffland[group == "res"]
```

```
par(mfrow=c(2,1))
```

```
hist(Restoration_BufferLandscape, xlim = c(0.2,1), col = "white")
```

```
hist(Reference_BufferLandscape, xlim = c(0.2,1), col = "grey")
```

```
Reference_Hydrology <-hydro[group == "ref"]
```

```
Restoration_Hydrology <-hydro[group == "res"]
```

```
par(mfrow=c(2,1))
```

```
hist(Restoration_Hydrology, main = "Hydrology of Restoration Sites", xlim = c(0.2,1), xlab
= "Hydrology Score", col = "white")
```

```
hist(Reference_Hydrology, main = "Hydrology of Reference Sites", xlim = c(0.2,1), xlab =
"Hydrology Score", col = "grey")
```

```
Reference_Physical <-phys[group == "ref"]
```

```

Restoration_Physical <-phys[group == "res"]
par(mfrow=c(2,1))
hist(Restoration_Physical, xlim = c(0.2,1), col = "white")
hist(Reference_Physical, xlim = c(0.2,1), col = "grey")

Reference_Biotic <-bio[group == "ref"]
Restoration_Biotic <-bio[group == "res"]
par(mfrow=c(2,1))
hist(Restoration_Biotic, main = "Biotic Structure of Restoration Sites", xlim = c(0.2,1),
xlab= "Attribute Score", col = "white")
hist(Reference_Biotic, main = "Biotic Structure of Reference Sites", xlim = c(0.2,1), xlab=
"Attribute Score", col = "grey")

# Metrics:
Ref_hper <-hper[group == "ref"]
Res_hper <-hper[group == "res"]
par(mfrow=c(2,1))
hist(Res_hper, main = "Restoration Site Channel Stability", xlim = c(0.2,1), xlab= "Metric
Score", col = "white")
hist(Ref_hper, main = "Reference Site Channel Stability", xlim = c(0.2,1), xlab= "Metric
Score", col = "grey")

Ref_plant <-plant[group == "ref"]
Res_plant <-plant[group == "res"]
par(mfrow=c(2,1))
hist(Res_plant, main = "Restoration Site Plant Community", xlim = c(0.2,1), xlab= "Metric
Score", col = "white")
hist(Ref_plant, main = "Reference Site Plant Community", xlim = c(0.2,1), xlab= "Metric
Score", col = "grey")

summary(test, as.factor(group))

```

#T-tests on Attributes and Metrics:

```
t.test(blarc~group, var.equal=TRUE)
t.test(hydroarc~group, var.equal=TRUE)
t.test(physarc~group, var.equal=TRUE)
t.test(bioarc~group, var.equal=TRUE)
t.test(lcArc~group, var.equal=TRUE)
t.test(buffarc~group, var.equal=TRUE)
t.test(h2arc~group, var.equal=TRUE)
t.test(hperacr~group, var.equal=TRUE)
t.test(hconnarc~group, var.equal=TRUE)
t.test(patcharc~group, var.equal=TRUE)
t.test(topoarc~group, var.equal=TRUE)
t.test(plantarc~group, var.equal=TRUE)
t.test(interarc~group, var.equal=TRUE)
t.test(vertarc~group, var.equal=TRUE)
t.test(CRAM~group, var.equal=TRUE)
```

# Summary stats (mean, sd, etc)

```
tapply(buffland, group, sd, na.rm=TRUE)
tapply(hydro, group, sd, na.rm=TRUE)
tapply(phys, group, sd, na.rm=TRUE)
tapply(bio, group, sd, na.rm=TRUE)
tapply(landconn, group, sd, na.rm=TRUE)
tapply(buff, group, sd, na.rm=TRUE)
tapply(h2source, group, sd, na.rm=TRUE)
tapply(hper, group, sd, na.rm=TRUE)
tapply(hconn, group, sd, na.rm=TRUE)
tapply(patch, group, sd, na.rm=TRUE)
tapply(topo, group, sd, na.rm=TRUE)
tapply(plant, group, sd, na.rm=TRUE)
```

```

tapply(inter, group, sd, na.rm=TRUE)
tapply(vert, group, sd, na.rm=TRUE)
tapply(CRAM, group, sd, na.rm=TRUE)
tapply(buffland, group, mean, na.rm=TRUE)
tapply(hydro, group, mean, na.rm=TRUE)
tapply(phys, group, mean, na.rm=TRUE)
tapply(bio, group, mean, na.rm=TRUE)

# DA without fish passage projects (file 2008_1010_fishx.csv)
# attributes: blarcf, hydroarcf, physarcf, bioarcf  metrics: lcarcf, buffarcf, etc.

fish<-read.csv(file.choose())
attach(fish)

# DA on attributes w/out fish sites
lda_attf<-lda(groupf~blarcf+hydroarcf+physarcf+bioarcf)
lda_attf

lda_metf<-
lda(groupf~lcarcf+buffarcf+h2arcf+hperarcf+hconnarcf+patcharcf+topoarcf+plantarcf+inter
arcf+vertarcf)
lda_metf

# MANOVA w/out fish sites
att.manf<-manova(cbind(blarcf, hydroarcf, physarcf, bioarcf)~groupf)
summary(att.manf, test = "Wilks")
met.manf<-
manova(cbind(lcarcf,buffarcf,h2arcf,hperarcf,hconnarcf,patcharcf,topoarcf,plantarcf,interarcf
,vertarcf)~groupf)
summary(met.manf, test = "Wilks")

```



```
# DA with plant sub-metrics included
plant<-read.csv(file.choose())
attach(plant)
lda_plant<-
lda(group~lcarc+buffarc+h2arc+hperacr+hconnarc+patcharc+topoarc+layarc+sparc+invarc+i
nterarc+vertarc)
lda_plant
man_plant<-
manova(cbind(lcarc,buffarc,h2arc,hperacr,hconnarc,patcharc,topoarc,layarc,sparc,invarc,inte
rarc,vertarc)~group)
summary(man_plant, test = "Wilks")
```

**APPENDIX C**

**SUMMARY STATISTICS**

| Metric/Attribute        | Restored<br>Mean | Restoration_stdev | Reference<br>Mean | Reference_stdev |
|-------------------------|------------------|-------------------|-------------------|-----------------|
| Buffer & Landscape      |                  |                   |                   |                 |
| Context                 | 0.786            | 0.182603          | 0.98              | 0.021066        |
| Hydrology               | 0.717            | 0.133354          | 0.917             | 0.06455         |
| Physical Structure      | 0.581            | 0.213629          | 0.903             | 0.06455         |
| Biotic Structure        | 0.631            | 0.146662          | 0.838             | 0.073054        |
| Landscape Connectivity  | 85.32609         | 0.251759          | 100               | 0               |
| Buffer                  | 71.92029         | 0.210172          | 95.45455          | 0.039893        |
| Water Source            | 77.71739         | 0.187214          | 95.45455          | 0.0625          |
| Channel Stability       | 65.21739         | 0.173664          | 92.04545          | 0.111803        |
| Hydrologic Connectivity | 72.82609         | 0.242712          | 87.5              | 0.157288        |
| Physical Patch          |                  |                   |                   |                 |
| Richness                | 57.6087          | 0.266053          | 88.63636          | 0.125           |
| Topographic             |                  |                   |                   |                 |
| Complexity              | 57.6087          | 0.224591          | 92.04545          | 0.085391        |
| Plant Community         | 74.63768         | 0.130625          | 90.15152          | 0.056928        |
| Interspersion &         |                  |                   |                   |                 |
| Zonation                | 52.71739         | 0.180413          | 75                | 0.15052         |
| Vertical Structure      | 63.58696         | 0.175455          | 86.36364          | 0.100778        |

## **APPENDIX D**

### **SITE LOCATIONS**

| Site   | Group    | Latitude   | Longitude   |
|--|----------|------------|-------------|
| Morro Bay State Park   | Restored | 35.3587    | -120.825641 |
| San Lorenzo  | Restored | 36.98199   | -122.02531  |
| Wilder Ranch State<br>Park Lombardi Creek<br>Revegetation  | Restored | 36.96643   | -122.11029  |
| Box Creek Restoration,<br>Zayante Area, SC<br>County, California                                 | Restored | 37.0681    | -122.0625   |
| Ano Nuevo State Park   | Restored | 37.14861   | -122.34669  |
| Andrew Molera SP   | Restored | 36.2869    | -121.8470   |
| Florence Street Bridge<br>retrofit (Toad Stream)   | Restored | 35.550545  | -120.710375 |
| Gaviota State Park<br>Riparian Restoration   | Restored | 34.4736    | -120.2293   |
| Linne Road Bridge,<br>Geneseo Low Water<br>Crossing  | Restored | 35.6010    | -120.6035   |
| Gazos Creek Uplands<br>Erosion Control Project   | Restored | 37.185     | -122.3506   |
| Quail Hollow Fishway   | Restored | 37.073889° | -122.0561   |
| San Jose Creek<br>Restoration Project  | Restored | 34.4472    | -119.823    |
| Scott's Creek<br>Watershed Council<br>Riparian Restoration<br>Project in Southern<br>Coho Stream | Restored | 37.0739    | -122.2369   |
| Pajaro River Watershed<br>Water Quality Program  | Restored | 36.97228   | -121.80188  |

|   |          |          |            |
|---|----------|----------|------------|
| Replacement of Salinas River Bridge on State Route 58             | Restored | 35.4096  | -120.5684  |
| Upper San Luis Obispo Creek Dam Removal                           | Restored | 35.3233  | -120.6227  |
| Kings Creek Fish Habitat Enhancement and Sediment Control Project | Restored | 37.17301 | -122.11834 |
| Wilder Creek Restoration Project                                  | Restored | 36.9678  | -122.0811  |
| Mesa Creek  | Restored | 34.4052  | -119.7392  |
| Fall Creek Fish Habitat Maintenance Project                       | Restored | 37.0514  | -122.0851  |
| San Simeon State Park Cape Ivy & Germany Ivy Eradication          | Restored | 35.5682  | -121.1041  |
| Gaviota SP  | Restored | 34.5077  | -120.2272  |
| Salsipuedes Creek Fish Passage Enhancement                        | Restored | 34.5967  | -120.4130  |
| Carpinteria Creek   | Restored | 34.3928  | -119.5143  |
| Mountain Charlie Gulch Instream Habitat Restoration               | Restored | 37.10475 | -122.01576 |
| Filipponi Revegetation Project -                                  | Restored | 35.2300  | -120.6833  |
| Caltrans: Salinas River Bridge Replacement                        | Restored | 35.6463  | 120.6629   |

|   |           |          |            |
|---|-----------|----------|------------|
| Gazos Creek Large<br>Gully Erosion Control<br>Project                 | Restored  | 37.1860  | -122.3539  |
| San Luis Obispo Creek<br>Rock Weir                                    | Restored  | 35.3173  | -120.6209  |
| Chumash Creek<br>Watershed<br>Enhancement Project                     | Restored  | 35.3436  | -120.7994  |
| Elkhorn Slough<br>Agricultural BMP<br>Demonstration (4-097-<br>253-0) | Restored  | 36.82666 | -121.73555 |
| Carmel River De<br>Dampierre Erosion<br>Control Project               | Restored  | 36.4836  | -121.7438  |
| Finch Creek Crossing<br>at Hallisey House,<br>Hastings Reserve        | Restored  | 36.3793  | -121.5658  |
| Bear Gulch Watershed<br>Upslope Erosion<br>Management Plan            | Restored  | 37.1900  | -122.2889  |
| Stenner Creek @<br>Highland Dr. (ST-2-4B)                             | Restored  | 35.3000  | -120.6706  |
| Queseria Creek Fish<br>Passage Improvement                            | Restored  | 37.04354 | -122.22273 |
| Arana Creek<br>Restoration Project                                    | Restored  | 36.9843  | -121.9923  |
| Thorne Rd. bridge<br>replacement                                      | Restored  | 36.32271 | -121.29331 |
| Browns Valley Rd.<br>Culvert Retrofit                                 | Restored  | 37.02488 | -121.78168 |
| Arroyo Hondo  | Reference | 34.48700 | -120.14220 |
| Gazos Creek   | Reference | 37.18730 | -122.32820 |
| EL CAPITAN  | Reference | 34.48049 | -120.01888 |

|  |           |          |            |
|--|-----------|----------|------------|
|  | Reference |          |            |
| Soberanes Creek                                |           | 36.45494 | -121.92099 |
| Sedgwick Reserve                               | Reference | 34.72113 | -120.03605 |
| Scotts Creek                                   | Reference | 37.07548 | -122.24190 |
| Carmel River                                   | Reference | 36.52243 | -121.81748 |
| San Antonio River                              | Reference | 35.89885 | -121.08314 |
| Arroyo De La Cruz                              | Reference | 35.70872 | -121.30145 |
| Upper San Simeon                               | Reference | 35.60904 | -121.07262 |
| Coon Creek                                     | Reference | 35.25500 | -120.88690 |
| Lower San Simeon                               | Reference | 35.59445 | -121.12024 |
| WEST WADDELL<br>CREEK                          | Reference | 37.17225 | -122.25105 |
| Lower Waddell                                  | Reference | 37.11254 | -122.27066 |
| NISENE MARKS                                   | Reference | 37.00229 | -121.90650 |
| CAVE GULCH                                     | Reference | 36.98808 | -122.07034 |
| LITTLE CREEK                                   | Reference | 37.06429 | -122.22573 |
| ANDERSON CANYON<br>(MCWAY)                     | Reference | 36.16241 | -121.66590 |
| BIG CREEK                                      | Reference | 36.07844 | -121.59476 |
| WHITEHOUSE CREEK<br>( ANO NUEVO STATE<br>PARK) | Reference | 37.16821 | -122.31807 |
| ARROYO SECO                                    | Reference | 36.22757 | -121.49422 |
| APTOS CREEK<br>(NISENE MARKS)                  | Reference | 37.02213 | -121.90412 |



**APPENDIX E**

**SITE PHOTOGRAPHS**

## Buffer Photos



Figure 1. Arana Creek fish ladder with buffer on right showing compacted soils and invasive weeds



Figure 2. Carpinteria Creek showing buffer with riparian plantings, restricted by adjacent urban development



Figure 3. Mesa Creek showing buffer restricted by road



Figure 4. Lombardi Creek showing buffer highly invaded by poison hemlock





Figure 5. Riparian zone on Blohm Ranch showing buffer adjacent to creek



Figure 6. Gazos Creek watershed in open space preserve with intact buffer

## Fish Passage Photos



Figure 7. Fish ladder on Corralitos Creek



Figure 8. Fish ladder on Arroyo Hondo Creek





Figure 9. Culvert replacement on a tributary to Arana Creek



Figure 10. Fish ladder on Zayante Creek

## Bank Stabilization Photos



Figure 11. Bank stabilization structure on Queseria Creek



Figure 12. Bank stabilization project on Corralitos Creek



## Reference Site Photos



Figure 13. Big Creek reference site with large woody debris



Figure 14. Gazos Creek reference site with diverse plant community (unconfined)





Figure 15. Sedgwick Reserve reference site in arid region



Figure 16. Arroyo Seco reference site

## ABSTRACT OF THE THESIS

### Evaluating River Restoration Success using the California Rapid Assessment Method

by

Cara Clark

Master of Science in Coastal and Watershed Science and Policy  
California State University Monterey Bay 2008

Although there has been significant expenditure on stream restoration, no unified monitoring and assessment strategy for these projects exists. This study evaluates California's success at improving stream condition by assessing state-sponsored restoration projects and comparing them to high quality reference sites using the California Rapid Assessment Method (CRAM). CRAM evaluates stream condition using universal attributes that are each evaluated with specific metrics. Restoration sites were randomly selected from a database of restoration projects in California Regional Water Quality Control Board Region 3, the Central Coast. Reference sites were chosen to characterize the best attainable condition in the region. CRAM scores for restoration sites were significantly lower than for reference sites ( $p < 0.001$ ). Discriminant analysis showed that the overall hydrology attribute and specifically the channel stability metric were the most important variables in distinguishing between restoration and reference sites. When fish passage projects were removed from the analysis, the buffer metric was targeted in the discriminant analysis. Physical structure metrics had the largest difference in means between restoration and reference sites. Practitioners have been most successful in restoring landscape and biological aspects of streams. Future restoration efforts should provide adequate buffer and aim to restore fully functioning hydrology and physical attributes. This study shows how CRAM can be used to monitor and assess river restoration projects to improve future efforts. The next steps are to build a dataset of pre- and post-restoration CRAM assessments, and to gather support for standardized monitoring among restoration practitioners and funding agencies.